## REPORT DOCUMENTATION PAGE

AFRL-SR-BL-TR-00-

0669



| 1. AGENCY USE ONLY (Leave blank) | 2. REPORT DATE | 3. REPORT TYPE AND DATES COVERED |
|---|---|---|
| | 22/11/00 | Final Report |

**4. TITLE AND SUBTITLE**
STRUCTURE-BASED TURBULENCE MODEL

**5. FUNDING NUMBERS**
F49620-95-1-0357

**6. AUTHOR(S)**
W.C. Reynolds

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Department of Mechanical Engineering
Stanford University
Stanford, CA 94305

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
AFOSR
801 N. Randolph St., Rm 732
Arlington VA 22203

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

**11. SUPPLEMENTARY NOTES**

**12a. DISTRIBUTION AVAILABILITY STATEMENT**

Approved for public release; Distribution Unlimited

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** *(Maximum 200 words)*
During the period of this award, the basic structure-based model for rapid distortions of homogeneous turbulence was extended to deal with slow distortions and inhomegeneities. A computer program was written to study the extended model in free-serar flows. Thc model was installed in NASA's INS2D code for generalized flow analysis. Mr. Maire carried out this work as part of his Phi) research. During the award period we began to explore ways to simplify the structure-based modeling so that it could be used in repetitive engineering calculations. The idea is to use an algebraic version of the model that, gives the turbulent, streses in terms of the mean strain rate and mean and frame rotation rates as an alternative to the linear or non linear stres strain relationships used in conventional two equation modeling. The difference would be that the algebraic structure-based turbulence model (ASBM) would do a much better job of representing the streses in complex flows. Development of this concept into a working engineering model and codes will be the principal objective under subsequent awards.





| 14. SUBJECT TERMS | 15. NUMBER OF PAGES |
|---|---|
| STRUCTURE-BASED TURBULENCE MODEL | 16. PRICE CODE |

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| UNCLASSIFIED | UNCLASSIFIED | UNCLASSIFIED | |

CAN NOT FIND FOLDERS 11/6/00

3484/WS Beutn

30 OCT 2000

**Final Technical Report**
**Structure-Based Turbulence Model**
**AASERT augmentation by AFOSR-95-1-0357**
**Award period 1/5/95-4/30/98**

W. C. Reynolds, Principal Investigator
Department of Mechanical Engineering
Stanford University
Stanford, CA 94305

## Objectives and approach

Turbulence modeling is the limiting factor in the ability of aerospace engineers to predict turbulent flows of importance in aircraft and propulsion system design. The objective of this program is to make a significant advance in the quality of aerospace engineering turbulence predictions through the development of a new type of turbulence model.

Current engineering models (*e.g.* $k$-$\varepsilon$ models) relate the turbulent stresses to the local mean deformation *rate* through an eddy viscosity. Such models are valid in the limit of slow deformation rates, but do not do well in complex non-equilibrium flows where the turbulence is rapidly deformed by the mean motion. Rapid Distortion Theory (RDT) does describe the response of the stresses to rapid mean deformations. Under RDT the stresses are determined not by the instantaneous strain *rates* but instead by the total *amount* of mean deformation. RDT is a closed two-point theory, but engineering models require one-point formulation. Therefore, what is needed is a one-point model that matches eddy viscosity models for weak deformation rates and RDT for rapid deformations. This would require a good one-point RDT model, and building such a model might seem to be a formidable challenge.

However, a very effective one-point structure-based model for RDT of homogeneous turbulence was developed by Kassinos and Reynolds (1994), hereafter denoted by KR, under previous AFOSR support. This RDT model is now being used as the backbone for a general structure-based turbulence model of the type described.

The new *structure-based* model is based on substantially more physics than in existing models. The turbulent stresses, which are needed in the CFD codes that predict the mean flow, are related to parameters of the turbulence structure, which are then evolved using transport equations developed from the underlying Navier-Stokes equations. These structural parameters evolve differently under slow and rapid deformations, and by representing the stresses in terms of the structure both regimes are captured correctly.

This AASERT award supported the initial PhD work of Mr. Scot Haire. That work continues under subsequent AFOSR suport.

## Accomplishments

During the period of this award, the basic structure-based model for rapid distortions of homogeneous turbulence was extended to deal with slow distortions and inhomogeneities.

Shear

A computer program was written to study the extended model in free-~~serar~~ flows. The model was installed in NASA's INS2D code for generalized flow analysis. Mr. Haire carried out this work as part of his PhD resarch.

During the award period we began to explore ways to simplify the structure-based modeling so that it could be used in repetitive engineering calculations. The idea is to use an algebraic version of the model that gives the turbulent streses in terms of the mean strain rate and mean and frame rotation rates as an alternative to the linear or non-linear stres-strain relationships used in conventional two equation modeling. The difference would be that the algebraic structure-based turbulence model (ASBM) would do a much better job of representing the streses in complex flows. Development of this concept into a working engineering model and codes will be the principal objective under subsequent awards.

The full details of the more recent structure-based modeling work will be reported in the PhD Dissertation Scot Haire, which we expect to complete under subsequent AFOSR support. Partial details have and will appear in various conference proceedings

### Personnel

- Prof. W.C. Reynolds, Principal Investigator
- Dr. S.C. Kassinos, Postdoctoral Investigator
- Mr. Scot Haire, PhD student (AFOSR-AASERT support)

### Discoveries, inventions, patent disclosures

No patentable discoveries.

### Honors and awards

- During the award period, Prof. W.C. Reynolds was elected to the American Academy of Arts and Science and was the 1995 W.R. Sears Distinguished Lecturer at Cornell University.
- Prior to the award period, Prof. W.C. Reynolds was elected to the National Academy of Engineering (1978), Fellow of the ASME, and Fellow of the APS, and received the Otto Laporte Award from the APS, the Fluids Engineering Award from the ASME, and the G. Edwin Burkes Award and a Centenary Award from the ASEE.

### Publications

Reynolds, W.C. & Kassinos, S.C 1995 One-point modeling of rapidly deformed homogeneous turbulence. To appear in *Proc. Roy. Soc. A* in a special Osborne Reynolds Centenary Issue.

Papers on the KR work is being prepared for submission to *J. Fluid Mechanics.*

### Reference

Kassinos, S.C. & Reynolds, W.C. 1994 A structure-based model for the rapid distortion of homogeneous turbulence. Report TF-61, Thermosciences Division, Department of Mechanical Engineering, Stanford University.